Energy Research and Development Division
FINAL PROJECT REPORT

THE ICHTHYOPLANKTON OF KING HARBOR, REDONDO BEACH, CALIFORNIA 1974-2006

Prepared for: California Energy Commission
Prepared by: Vantuna Research Group and Occidental College

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PREFACE

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The ichthyoplankton of King Harbor, Redondo Beach, California 1974-2006 is the final report for the Environmental Effects of Cooling Water Intake Structures Project (contract number 500-04-025), conducted by the University of California, Santa Cruz. The information from this project contributes to the Energy Research and Development Division's Energy-Related Environmental Research Program.

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ABSTRACT

In this project, the ichthyoplankton (fish eggs and larvae) of King Harbor, Redondo Beach, California was monitored from 1974 to 2006 on a monthly basis by the Vantuna Research Group. The larval community significantly changed during the monitoring period. There were three major annual groupings of fish larvae: 1974-1977, 1978-1994 and 1995-2006. The larval assemblage of King Harbor did not return to the pre-1978 condition, but instead it continued to move on a trajectory away from the cold phase of the Pacific Decadal Oscillation. Macro scale oceanographic processes (the El Niño-Southern Oscillation, the Pacific Decadal Oscillation and the Southern California Bight sea surface temperature were not significant factors in the change in larval densities over time. The major factor in the change over time was a long-term decline in larval catch, which resulted in part from declining nearshore productivity. Larval catch was statistically similar between the VRG King Harbor study and the Redondo Beach Generating Station's entrainment characterization survey. Using change among years in larval density as a factor, a minimum three-year interval would be necessary to describe the change in this larval community.

Keywords: ichthyoplankton, larval fish, Santa Monica Bay, time series, productivity

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EXECUTIVE SUMMARY

Introduction

Once-through cooling technology requires diverting and then discharging millions of gallons of water daily. Carried along in this flow of water are millions of small aquatic organisms that are killed as they flow through the cooling system from exposure to heat and chemicals. Although this cooling technology has been used in California for over 50 years, the impact on marine ecosystems is still not well understood.

Power plants in California using once-through cooling are subject to provisions of the Clean Water Act. Specifically, Section 316(b) of the act requires that the location, design, construction, and capacity of cooling water intake structures reflect the best technology available to protect aquatic organisms from being killed or injured by impingement (being pinned against screens or other parts of a cooling water intake structure) or entrainment (being drawn into cooling water systems and subjected to thermal, physical or chemical stresses).

Project Purpose

To understand the effect of power plant entrainment on marine ecosystems, entrainment characterization studies have been conducted for each facility. These studies are typically conducted over a single year and are usually focused on the most abundant, economically important, and/or managed species. This approach leads to two critical unanswered questions that hamper understanding the ecological effects of coastal generating stations in California. First, what is the overall community being impacted? Second, how sensitive is this community to temporal variation? Since neither of these questions can be answered with a single year of data, this study extended and analyzed a unique long-term nearshore database to answer these questions.

Project Results

Since 1974, stratified, monthly plankton (any drifting organisms in the water) samples were conducted in King Harbor, Redondo Beach. This monitoring program is unique because it provided the only long-term nearshore ichthyoplankton data set in the Southern California Bight. Ichthyoplankton are young fish that drift in the water and are morphologically different from mature adults. The Southern California Bight refers to the coastal waters stretching from Point Conception in Santa Barbara County to just below the Mexican border.

This long-term data set was also located close to three coastal generating stations using once-through cooling and can shed light on the effects from the massive use of cooling water by those power plants. This was shown by the fact that larval samples were statistically similar between the results of this study and the Redondo Beach Generating Station’s entrainment characterization survey.

This report characterizes how this ichthyoplankton community has changed over time and how sensitive this community is to change. This information is also important in determining how frequently power plant entrainment studies should be conducted to capture changes in the fish larva community.

To facilitate analyzing long-term changes, annual sampling results were statistically analyzed for similarities. Based upon this analysis, three major annual groupings were identified: 1974-1977, 1978-1994 and 1995-2006. Catch in the 2006 sampling season was consistent with the final group. This analysis clearly showed that the larval community has significantly changed over the 33-year data collection period.

Over this period, study results show that not only did the larval community change, but that overall larval density significantly declined. The abundance of nearly all the individual species also declined over this period. Factors explaining these changes that were evaluated in this study include changes in ocean-atmospheric patterns, such as El Niño-Southern Oscillation events that involve the depression of oceanographic thermoclines (the boundary between warmer upper water and colder water below), severe reductions of nutrient input, and changes in storm patterns as well as sea surface water temperatures in Santa Monica Bay, the water body just outside King Harbor. Other factors considered in this larval density decline were changes in nutrient levels and changes in ecosystem productivity. Nitrogen and silicate levels were used to determine nutrient levels while kelp bed coverage, which is also determined by the influx of nutrients into the nearshore environment, was used as a proxy for ecosystem productivity.

Results showed that large scale oceanographic processes such as the El Niño-Southern Oscillation and the Pacific Decadal Oscillation (another water-atmosphere interaction that changes over long periods of time) were not significant factors in the change in larval densities over time. While sea surface water temperatures for Santa Monica Bay varied in response to the large scale water-atmospheric processes such as the El Niño-Southern Oscillation, it did not correlate with changes in overall larval abundance.

The long-term decline in larvae abundance correlated to nearshore productivity declines as indicated by changes in nutrient loads and in giant kelp coverage. The statistically significant nearshore factor that correlated with larval catch was nitrogen levels. This correlation, however, was a negative one where increased detectable nitrogen levels meant decreased larval densities. The kelp coverage was also determined by the influx of nutrients into the nearshore environment and it served as a proxy for production and correlated with the increase in larvae for many nearshore species.

Some individual larval taxa (a group of related organisms) responded quite differently from other species over the time series. Several species were affected by red tides while other species were influenced by power plant flow rates.

A major question this study addressed was the appropriate frequency of power plant entrainment studies. Since these studies only cover one year and may not be repeated for many years, the question is how often should these studies be conducted to capture the variability displayed by the King Harbor data? Since the pair data collected during the King Harbor study and a power plant entrainment study were correlated, a statistical analysis was used to determine if the replication (repetition) within a year at King Harbor was high enough to detect the significant interannual (between year) decline in overall larval catch. Based upon this analysis, a three-year interval was a conservative estimate required to detect this change over time.

Project Benefits

This long-term study provided the only long-term nearshore ichthyoplankton data set in the Southern California Bight. The study results can be used for understanding the ecological effects of coastal generating stations in California that use once-through cooling technology and in determining how often power plant entrainment studies should be conducted to capture changes in the fish larva community.

Chapter 1: Introduction

The impact of using once-through cooling technology on marine ecosystems is not well understood despite having been used in California for over 50 years. On February 16, 2004 the United States Environmental Protection Agency (USEPA) published environmental regulations under the Clean Water Act, Section 316 (b) that required once-through cooled generating stations to utilize the best available technology to protect aquatic organisms. This act required that impingement of organisms be reduced by 80-95 percent and entrainment 60-90 percent from baseline levels. This rule was suspended by USEPA in March 2007 after substantial provisions were successfully challenged by Riverkeeper, Inc. in the United States Second Circuit Court.

In order to meet the reduction goals originally promulgated in the USEPA rule, a more thorough understanding of the ecology of these systems must be developed. Anthropogenic impacts may be difficult (or impossible) to detect without sufficient baseline data that provides information on the natural variability of a system. This requires adequate sampling over an extensive time period encompassing ecological phenomena known to impact marine ecosystems. The El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) have dramatic effects on the marine systems on the entire Pacific Coast of North America. The ENSO effects are most prominent in the tropics and the PDO in the Temperate North Pacific. Southern California occurs in a transition zone and is likely affected by the interaction between ENSO and PDO. Therefore, understanding natural ecological variability for a system should include sampling that encompasses both ENSO events and shifts in the PDO.

Typically, Clean Water Act Section 316(b) entrainment characterization studies have been conducted over a single year and usually are focused only on the most abundant, economically important, and/or managed species. This leads to two critical unanswered questions which hamper the understanding of the ecological effects of our coastal generating stations: First, what is the overall community being impacted? Second, how sensitive is this community to temporal variation? Since neither of these questions can be answered with a single year of data, this study extended and analyzed a unique long-term nearshore database to answer these questions.

The ichthyoplankton of King Harbor, Redondo Beach, California has been monitored monthly utilizing the same methodology since 1974 (Stephens et al. 1986; Stephens and Pondella 2002). Density of larval fishes and plankton has decreased substantially during this 30 year sampling period (Stephens and Pondella 2002). Roemmich and McGowan (1995) described an 80 percent decrease in zooplankton volume in the California Current off southern California since 1951 and the most precipitous decline occurring after the 1970's (McGowan et al. 1998). However, the California Cooperative Oceanic Fisheries Investigations (CalCOFI) data set is not collected in the nearshore environment (Moser and Watson 2006) and as such, its applicability for describing the nearshore ichthyoplankton community is limited. The extensive King Harbor data base may provide greater resolution into the natural variability of this ecosystem. This monitoring program is unique because it is the only long-term nearshore ichthyoplankton data set in the Southern California Bight. It is also uniquely set proximate to three coastal generating stations withdrawing seawater from the southern one-half of the Santa Monica Bay: Redondo Generating Station (RBGS), El Segundo Generating Station and Scattergood Generating Station (Figure 1). Thus, the authors decided to temporally analyze this data set to describe the entire ichthyoplankton community in this nearshore environment and determine how sensitive this community is to change. This temporal analysis will be critical in determining how frequently an entrainment assessment needs to be completed.

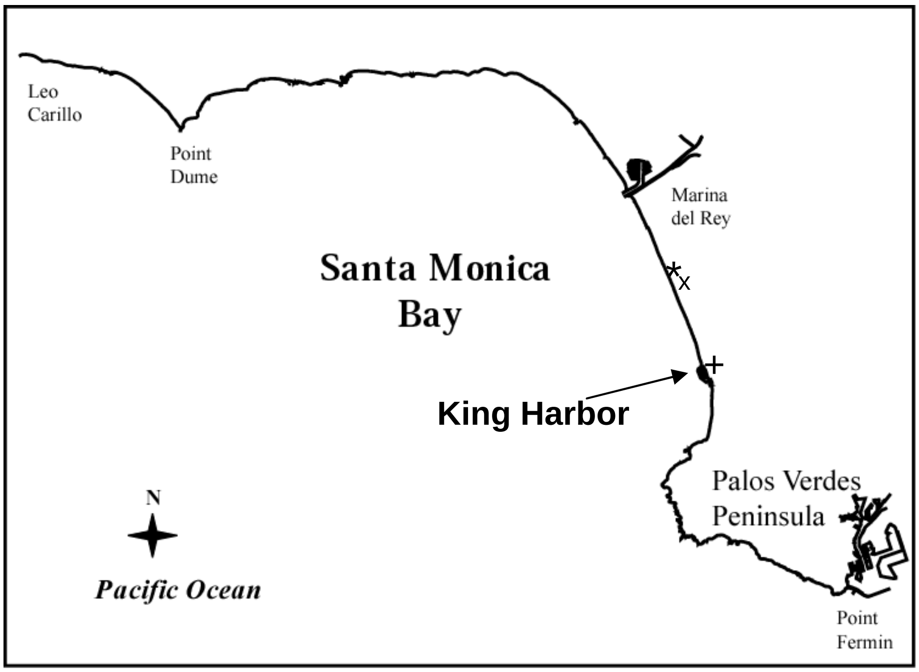


Figure 1. Santa Monica Bay including the locations of the Redondo Beach Generating Station (+), El Segundo Generating Station (x) and Scattergood Generating Station (*).

1.1 Field Work

Since 1974, stratified, monthly plankton samples have been conducted in King Harbor, Redondo Beach. Plankton tows are conducted at five stations (Figure 2) and collections are made with a 333-μm mesh standard conical meter net fitted with a TSK flowmeter. Three levels of vertically stratified samples are taken during each sampling period: surface (upper 2 m), mid-depth (4-6 m), and bottom (9-10 m). Bottom samples are taken with a meter net attached to an epibenthic sled while surface samples are collected using a modified meter net sampler. Surface samples are taken at night, while mid-depth and bottom strata are sampled diurnally. Samples are preserved in a 5 percent formaldehyde-borate solution and subsequently sorted to the lowest possible taxon. Station D has only been sampled at the surface.

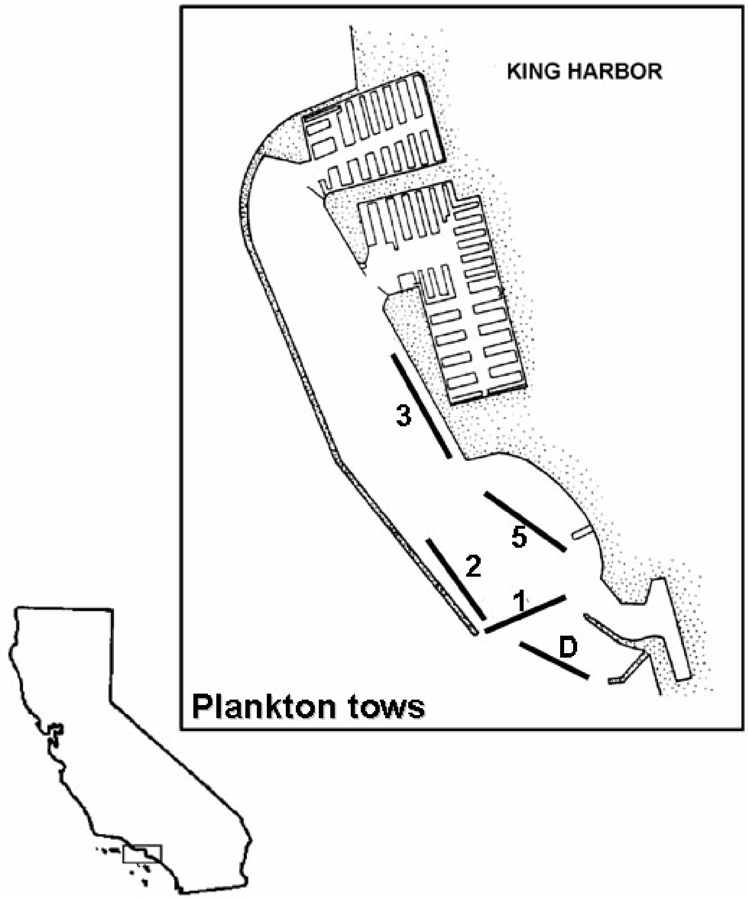


Figure 2. King Harbor, Redondo Beach California. Diurnal plankton tows are conducted at stations 1, 2, 3 & 5 while night, surface tows are made at all stations (1, 2, 3, 5 & D).

1.2 Community Time Series Analyses

From 1974-1977, only Station D was sampled. The surface at Station 1 was sampled from 1978-2006, while Station D was not sampled from 1978-1980. Considering the proximity of these stations and incomplete sampling over the entire time series, the surface night samples at Station 1 and Station D were combined to generate the 1974-2006 time series data set. Mid-depth and bottom samples were not used because they were not sampled in every year of the time series. Furthermore, late stage larvae (flexion, post flexion and juvenile) were used in the time series analyses. Older larvae, having survived the highest mortality stages of their life history, should give a better estimate of eventual recruitment and contribution to the adult population. Prior to analyses, larval abundances were standardized to the volume of water sampled.

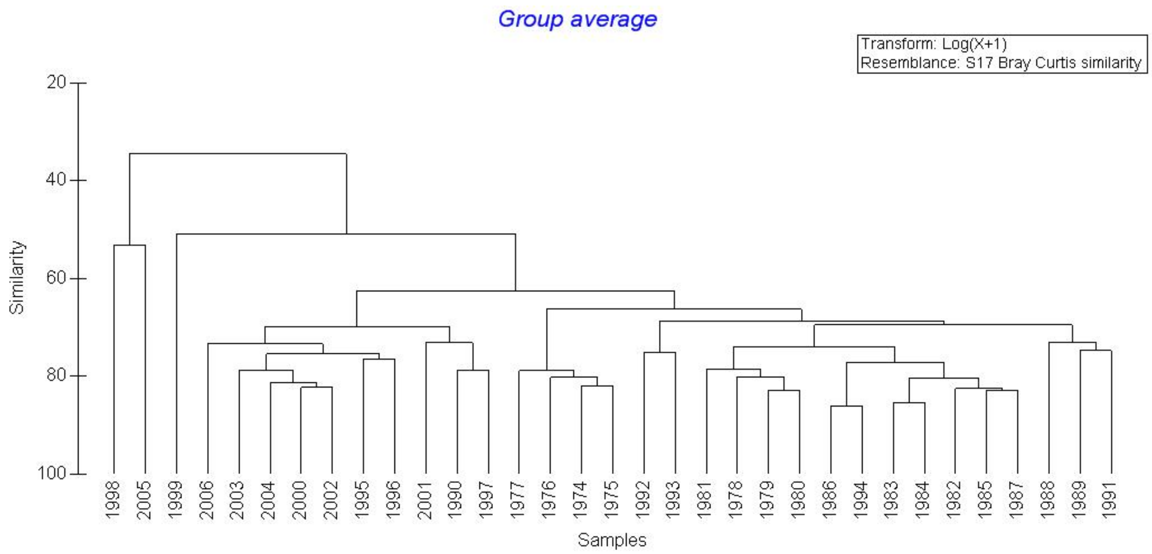
Community analyses were conducted in PRIMER (Version 6.1.10) using the following routines. First the annual mean larval abundance by taxa was calculated in Excel. Based upon the overall cumulative catch, the annual mean density top 99 percent of larval taxa were imported to PRIMER. The data were then Log (x+1) transformed and hierarchically clustered using the Bray-Curtis similarity index. The subsequent matrix was then presented in a two dimensional plot using non-metric multi-dimensional scaling (MDS) with overlaid clusters of the groups identified from the Bray-Curtis cluster dendogram. These groups were then tested for differences using the ANOSIM procedure. To further explore the contribution or influence of particular taxa to the MDS ordination, the annual density of the abundant taxa were overlaid for visual reference. These taxa and the total larval density were examined for trends using linear regression and then modeled using 11 factors (1974-2006: SST, ENSO, PDO, Upwelling and Palos Verdes giant kelp canopy [*Macrocystis pyrifera*]; 1985-2006: SST and D.O. in Santa Monica Bay; 1984-2006: chlorophyll a, NO_2, SiO_3, and 1978-2006: flow from RBGS) using a forward stepwise multiple linear regression model. Linear regression and all other statistics were run in Statistica (Version 8.0).

Chapter 2:
King Harbor Ichthyoplankton Community 1974-2006

From 1974-2006, 99 late stage (SL, FL, JV) larval taxa were identified. *Hypsoblennius* sp. was the dominant taxa comprising 35.71 percent of the catch. This was followed by *Hypsypops rubicundus* (14.36 percent), *Genyonemus lineatus* (10.10 percent), Goby A/C complex (8.11 percent), *Engraulis mordax* (7.77 percent), *Lythrypnus* sp. (5.80 percent) and *Seriphus politus* (3.56 percent). The top 34 taxa comprised 99 percent of the catch over the 33 year time series (Appendix A) and these taxa were used in the community assessment. There were three significant (ANOSIM; $P < 0.001$) clusters as shown in the Bray-Curtis cluster and MDS ordination plots (Figure 3). The first cluster was 1974-1977, followed by 1978-1994 (excluding 1990) and 1995-2006 plus 1990 and excluding 1998, 1999 and 2005. The last three years formed individual groupings with 1999 being most similar to the 1995-2006 cluster. There was a clear chronological trajectory starting in 1974 and continuing through 2006, where the assemblage changed in a temporal framework continually during this 33-year time period. The 2006 sampling season fell at the tail end of the third major group. Thus, the time frame of the recent entrainment assessments in the region can be viewed in reference to the previous decade, but not the two decades prior.

Overall larval density declined significantly during the time series ($R = 0.673$, $F_{1,31} = 25.69$, $p < 0.001$; Figure 4). Using a power goal of 90 percent ($\alpha = 0.05$) a minimum of 17 replicates per sampling period were needed to describe this interannual variation. Further a 3 year annual interval is a conservative estimate required to describe this trend ($F = 9.74$, power goal = 90 percent, $\alpha = 0.05$). From 1974-1978, 2.1-3.6 larvae/m^3 were being captured, with the highest catches in 1975 (3.6 ± 0.9/m^3) and 1977 (2.9 ± 0.3/m^3) with lowest catches coming in 1998 (0.2 ± 0.06/m^3) and 2005 (0.08 ± 0.03/m^3). Two of the outliers identified in the MDS ordination were 1998 and 2005. The overall trend of reduced larval supply appears to be the best explanation of the MDS ordination. Using the stepwise forward multiple regression model (Table 1), the most important factor contributing to this decline in density was a negative correlation with nitrates in Santa Monica Bay ($p = 0.037$). The primary factors in the model are associated with production. Thus a long-term decline in productivity may be the best explanation for this decline.

This decline is evident when examining the trends for the top seven taxa in the study (See Figures 5-11, starting on page 18). All but *Hypsypops rubicundus* significantly declined over the course of the study (Figure 12 on page . Taxa primarily followed the pattern seen in the overall larval decline as was observed for



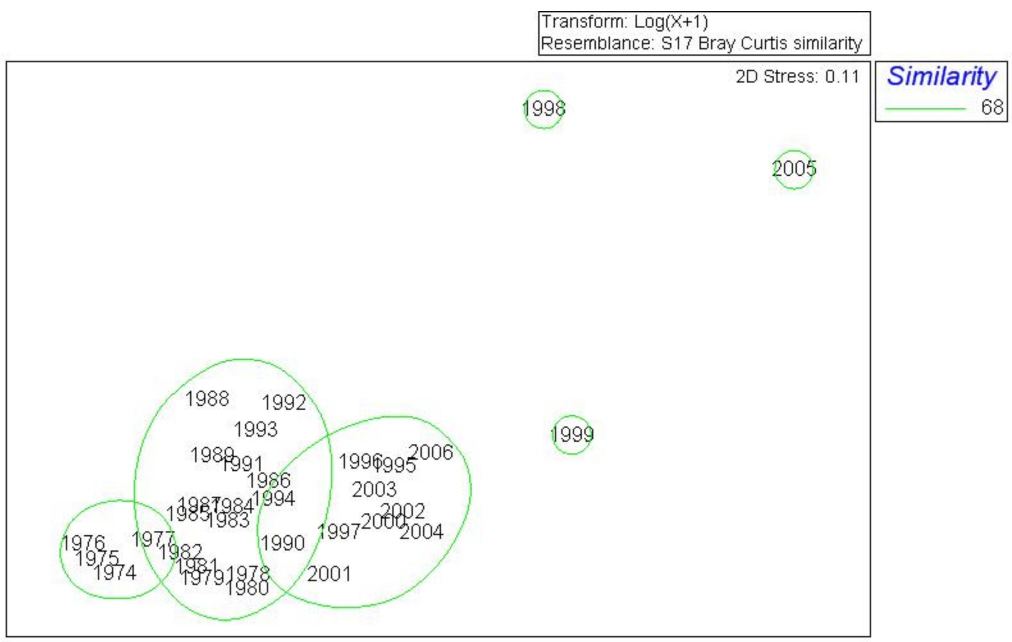


Figure 3. The following Bray-Curtis similarity cluster and MDS ordination were produced from the mean annual larval density of the 99% most abundant taxa at Stations 1 and D (surface night tows only) from 1974-2006.

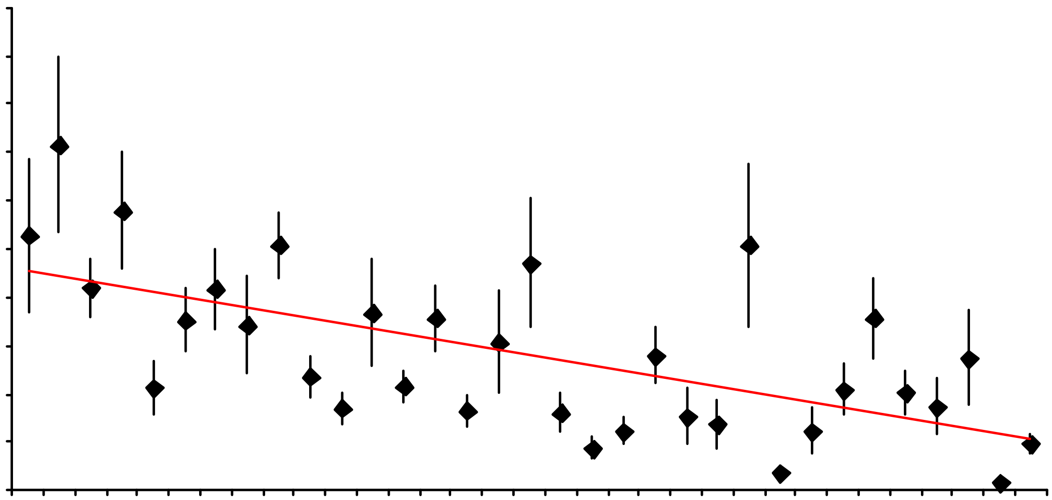


Figure 4. Overall larval density (#/1000 m^3) from 1974-2006, the regression line is in red. The error bars are 1 S.E.

Hypsoblennius, *Genyonemus*, *Engraulis*, Goby A/C, and *Seriphus*. This pattern can be observed easily in the individual plots as well as in the bubble overlays on the MDS ordination. This was expected because these were the primary taxa driving that trend. However, each taxa reacted independently. *Lythrypnus* sp. was nearly absent from 1974-1977, increased dramatically though 1991 and then declined precipitously through 2006. *Hypsypops rubicundus* larvae fluctuated dramatically. They were absent from 1974-1976 and then oscillate greatly for the next three decades.

Hypsypops rubicundus is a nesting reef fish that lives on the jetties and groins that comprise the marina. After the eggs hatch the larvae are released from the male's nest and become primarily neustonic. In 2006, the larvae were present from May-August peaking in June and July (Figure 12, page 25) and the VRG and RBGS studies were significantly correlated ($R = 0.619$, $p = 0.033$). Thus, larval densities in this species are likely to be tied to nesting success as well as oceanographic factors. In 2005, there were extensive red tides and fish kills in King Harbor, thus it is not surprising that larval density crashed that year. We also observed red tides in King Harbor in 1998 perhaps resulting in the poor production then. While *Hypsypops* did extremely well in 1997 during the large El Nino, the variation in larval catch was not a factor of the ENSO index (Table 1). Instead characteristics of production (NO_2, O_2 and chlorophyll a) in Santa Monica Bay were the significant factors in the forward stepwise multiple regression model. While nesting/reproductive success is obviously a critical factor for any vertebrate, other than episodic events, nearshore production drove the success of *Hypsypops* larvae.

Table 1. Forward stepwise multiple regression model outputs; significant factors are in red.

***Hypsoblennius* sp.**

R = 0.701, $F_{2,18}$ = 8.6981, p < 0.00227

Factor	Beta	B	p-level
NO_2	-0.74	-34.04	0.000574
O_2	-0.23	-5.69	0.208513

Hypsypops rubicundus

R = 0.669, $F_{3,1}$ = 4.5883 p < 0.01575

Factor	Beta	B	p-level
NO_2	-0.79	-60.64	0.002243
O_2	-0.78	-31.98	0.027171
Chl a	0.51	2.83	0.117726

Genyonemus lineatus

R= 0.803, $F_{3,17}$ = 10.290 p < 0.00043

Factor	Beta	B	p-level
Flow	0.52	2.45	0.003930
PV Kelp	0.48	3.19	0.007061
SIO_3	-0.17	-1.74	0.270931

Engraulis mordax

R= 0.999, $F_{4,16}$ = 35168, p < 0.0000

Factor	Beta	B	p-level
Upwelling	1.00	0.14	0.000000
SIO_3	0.01	0.00	0.039509
ENSO	0.01	0.00	0.087266
SST	0.00	0.00	0.250083

Goby A/C

R= 0.842, $F_{5,15}$ = 7.3128, p < 0.00119

Factor	Beta	B	p-level
Flow	0.49	1.04	0.006323
SIO_3	0.29	1.34	0.072403
NO_2	-0.25	-9.85	0.136503
SST	0.21	4.66	0.192499
PV Kelp	0.16	0.48	0.337619

Seriphus politus

R= 0.863, $F_{5,15}$ = 8.7341 p < 0.00048

Factor	Beta	B	p-level
PV Kelp	0.64	3.77	0.002280
Flow	0.44	1.83	0.048062
O_2	0.25	10.58	0.193943
PDO	-0.19	-1.52	0.214771
SMB SST	0.23	7.15	0.222695

***Lythrypnus* sp.**

R = 0.863, $F_{4,16}$ =11.715 p < 0.00012

Factor	Beta	B	p-level
PV Kelp	0.48	2.97	0.003738
Flow	0.38	1.66	0.014567
NO_2	-0.24	-19.41	0.101981
PDO	-0.17	-1.39	0.221989

Total Larvae

R = 0.794, $F_{6,14}$ =3.9692, p < 0.01574

Factor	Beta	B	p-level
NO_2	-0.60	-22.28	0.037209
Upwelling	0.39	2.00	0.069063
O_2	-0.72	-14.39	0.121450
SST	0.34	7.20	0.169989
Chl a	0.36	0.98	0.328886
Flow	0.09	0.17	0.769843

The blennies, *Hypsoblennius* sp., also nest in King Harbor prior to the release of planktonic larvae. They were present in the larval community from March-November, peaking in abundance from May-August and both series of collections were significantly correlated ($R = 0.715$, $p = 0.009$; Figure 13). This was the most abundant larval group caught consistently throughout the 33-year time series. The highs and lows in larval catch are strikingly similar to *Hypsypops*. The highest catch was in 1974 (there were no *Hypsypops* caught then), but then there are peaks in 1980, 1990, 1997, and 2001 and lows in 1984, 1998, and 2005 concomitant with the variation in *Hypsypops*. From 1977, the first year *Hypsypops* was caught, through 2006 larval catch of *Hypsypop*s and *Hypsoblennius* were highly correlated ($R = 0.778$, $p < 0.000001$). Thus, it was not surprising that NO_2 and O_2 were also the significant factors in the multiple regression model. *Hypsoblennius* catch declined significantly throughout the time series ($R = 0.489$, $F_{1,31} = 9.74$, $p = 0.004$) and this decline was a driver of the long term change in this larval community (Figure 5).

Croakers have generally epibenthic larvae after reaching the flexion stage. The two abundant taxa in this group, *Genyonemus lineatus* and *Seriphus politus*, both significantly declined (*Genyonemus*: $R = 0.835$, $F_{1,31} = 71.3$, $p < 0.000001$; *Seriphus*: $R = 0.889$, $F_{1,31} = 117.0$, $p < 0.000001$) and were essentially absent by the mid 1990's. As with *Hypsoblennius*, these declines were indicative of the community structure in the MDS ordination (Figures 7 and 10). Larval catch was high from 1974-1977, intermediate from 1978-1994 and low from 1995-2006. The significant factors that explained the declines of these nearshore benthic larvae were cooling water flow at the RBGS and maximum aerial giant kelp density from the Palos Verdes Peninsula (Table 1). Cooling water flow at RBGS was also a significant factor explaining the catch of the abundant goby taxa (Goby A/C and *Lythrypnus* sp.). Goby larvae, like the croakers, become epibenthic during the latter larval stages, yet the time series differs among the two taxonomic categories (Figures 9 and 11). Goby A/C complex followed the significant long term declines observed in the croakers ($R = 0.576$, $F_{1,31} = 15.4$, $p = 0.0004$). *Lythrypnus* had a markedly different pattern, starting with low catch from 1974-1977; it was abundant during the 1978-1994 period and then crashed towards the end of the time series. In addition to cooling water flow, Palos Verdes giant kelp maximum aerial coverage was also an indicator of *Lythrypnus* larval density (Table 1). Fishes with epibenthic larvae were influenced by nearshore ecosystem health (for which giant kelp coverage is a presumed proxy) and power plant cooling water flow. This last factor presents the possibility that the power plant effects the distribution of these nearshore larvae. How this occurs is an open inquiry, but the plant does pull in water from the midwater and bottom (Kinnetic Laboratories 1979), thus one hypothesis is that the flow was pulling this water body into the area, increasing the associated larval assemblage. Therefore, as the RBGS cooling water flow volumes declined with time, so too did the densities of epibenthic larvae within King Harbor. Bight-wide CalCOFI data, however, reports similar declines for some of these taxa, such as *Seriphus* (Moser et al. 2001 Atlas 34).

Engraulis mordax was the fourth most abundant larvae in this time series. Unlike the other taxa in this discussion, *Engraulis* is not a predominantly nearshore larval taxa. *Engraulis* did decline significantly ($R = 0.846$, $F_{1,31} = 78.0$, $p < 0.000001$; Figure 8). This decline reflected the community shifts in the MDS ordination. The catch of Engraulis was highest from 1974-1977, intermediate to low from 1978-1994, and low from 1995-2006. While *Engraulis* is an indicator species of the PDO, in this nearshore area the PDO was not an explanatory variable in the multiple regression model (Table 1). Instead local upwelling and silicates were the significant factors in the model.

Chapter 3: Conclusions

In general, the King Harbor ichthyoplankton community has largely declined in response to changes in coastal productivity, as indicated by nutrient loads (NO_2, SIO_3, O_2) and environmental proxies such as giant kelp vitality. Epibenthic larvae, such as the croakers and gobies, exhibited density trends commensurate with cooling water flow at the RBGS. As flow declined, their densities declined. Overall, the King Harbor ichthyoplankton community has declined with time, with nearly all species' densities being well below their previously sampled peaks.

To identify changes, annual sampling results were statistically analyzed for similarities. Based upon this, three major annual groupings were identified: 1974-1977, 1978-1994 and 1995-2006. Catch in the 2006 sampling season was consistent with the final group. The larval assemblage of King Harbor was not returning to the pre-1978 condition, instead it continued to move on a trajectory away from the cold phase of the PDO.

- Macro scale oceanographic processes (ENSO, PDO, Southern California Bight SST) were not significant factors in the change in larval densities over time. From 1974-2006 the annual mean temperature of Santa Monica Bay varied from a low of 14.92^0 C during the La Nina of 1999 to 17.76^0 C during the 1983-84 El Nino. The average annual temperature was 16.48^0 C. Larval density did not change with sea surface temperatures.
- The major factor in the change over time was a long-term decline in larval catch. The statistically significant nearshore factors that correlated with larval catch were nitrogen, upwelling and silicates. In California there is an inverse relationship between nitrogen and primary productivity. As it is sequestered by autotrophs during a bloom production increases as detectable nitrogen decreases. Thus, where nitrogen as a significant factor in the catch of larvae, it was negatively correlated with the increase in larval catch. Localized upwelling and silicates were important for anchovies. The Redondo Submarine Canyon is the source of local upwelling. The kelp coverage is also determined by the influx of nutrients into the nearshore environment. Thus, it was used as a proxy for production and correlated with the increase in larvae for many nearshore species.
- Individual larval taxa responded quite differently over the time series:
    - Nesting fishes (*Hypsypops and Hypsoblennius*) were influenced by red tides and nearshore productivity.
    - Factors that explained the catch of fishes with epibenthic larvae, croakers (*Genyonemus lineatus* and *Seriphus politus*) and gobies (Goby A/C complex and *Lythrypnus* sp.), were power plant flow and maximum aerial kelp density at Rancho Palos Verdes. When flow rates were greater, more larvae were caught

and more larvae were present when kelp density was high. No other larval types were influenced by flow rates.

    - Declines in *Engraulis mordax* were linked to nearshore productivity changes.

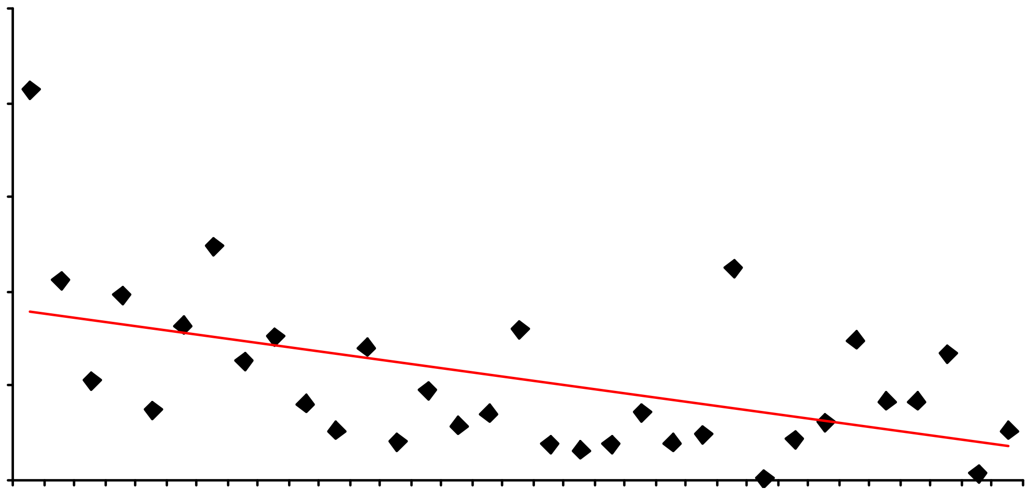
- Since there are no time series data associated with Clean Water Act Section 316(b) studies, the authors used the following model to analyze the frequency that an assessment would need to be completed for these power plants following this path.

  1) First question is whether the data collected during a Section 316(b) sampling study correlate to the data collected during this King Harbor study period?

  2) The second question is whether there enough replication in the sampling conducted at King Harbor to have confidence in the time series analyses?

  3) If questions 1 and 2 are satisfied: then the question becomes what is the annual sampling frequency needed to detect a change overtime?

  Since the response to question number 1 is yes, paired larval catches between the King Harbor and the Section 316(b) survey were correlated, the authors used a power analysis to determine if the replication within a year at King Harbor was high enough to detect significant interannual variation in overall larval catch. Using a power goal of 90 percent ($\alpha = 0.05$) a minimum of 17 replicates per sampling period were needed to describe this interannual variation and currently 24 replicates are conducted. 3) Overall larval density declined significantly during the time series ($R = 0.673$, $F_{1,31} = 25.69$, $p < 0.001$; See Figure 4). A 3 year annual interval is a conservative estimate required to detect this change over time ($F = 9.74$, power goal = 90 percent, alpha level = 0.05).



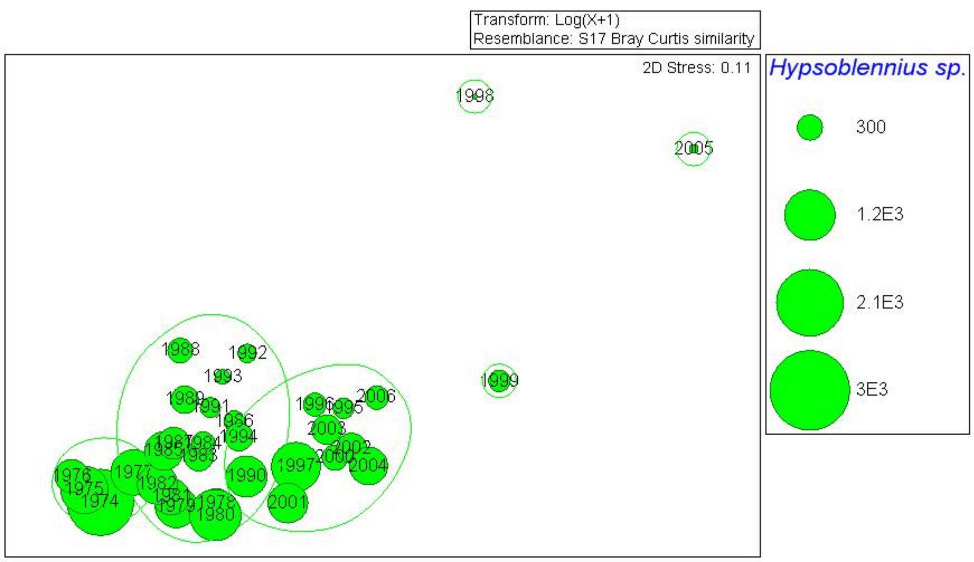
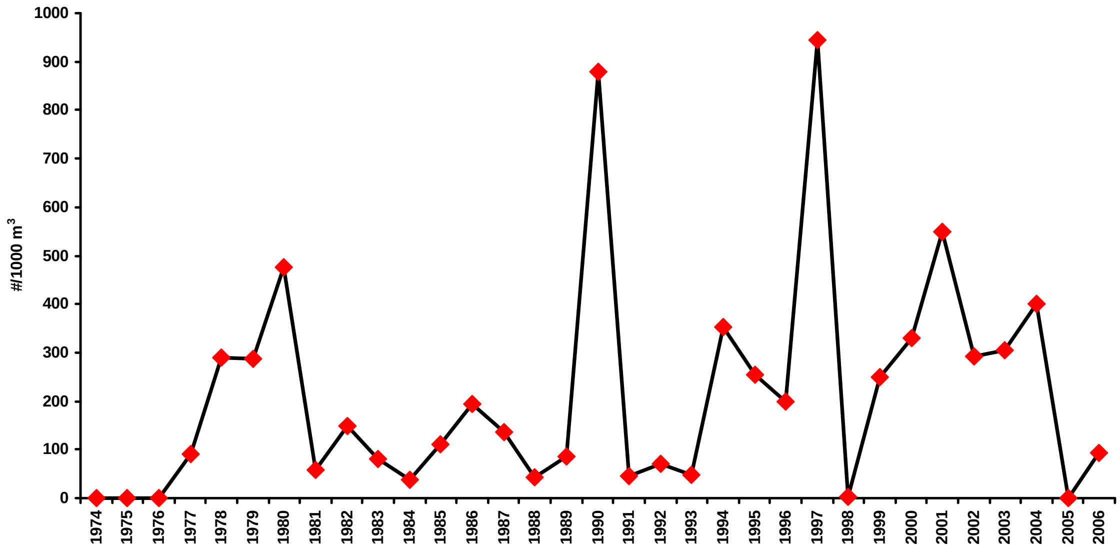


Figure 5. Above shows *Hypsoblennius* sp. larval density (#/1000 m^3) from 1974-2006, the regression line is in red. Below is a plot of an overlay of this density on the MDS ordination.



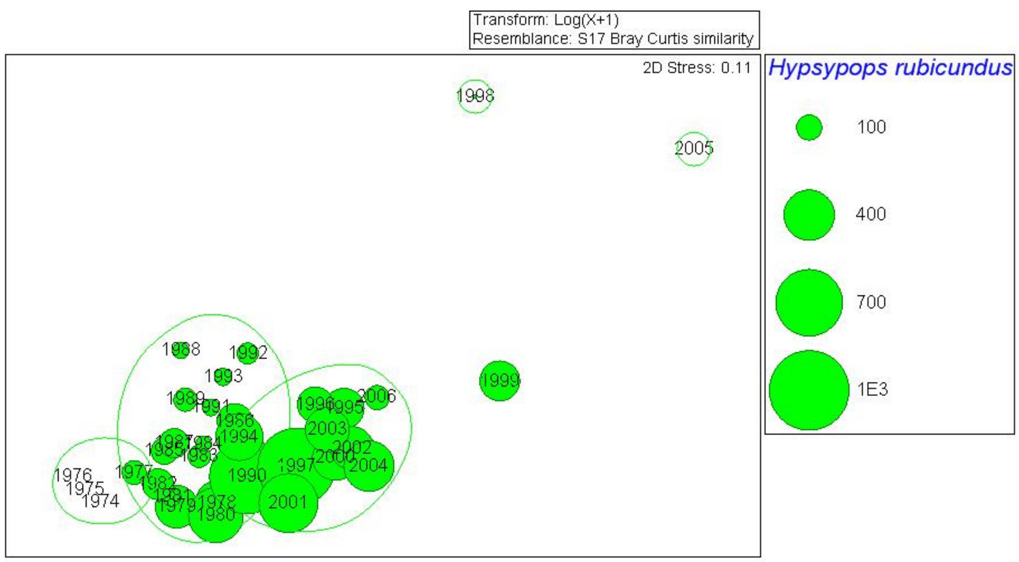
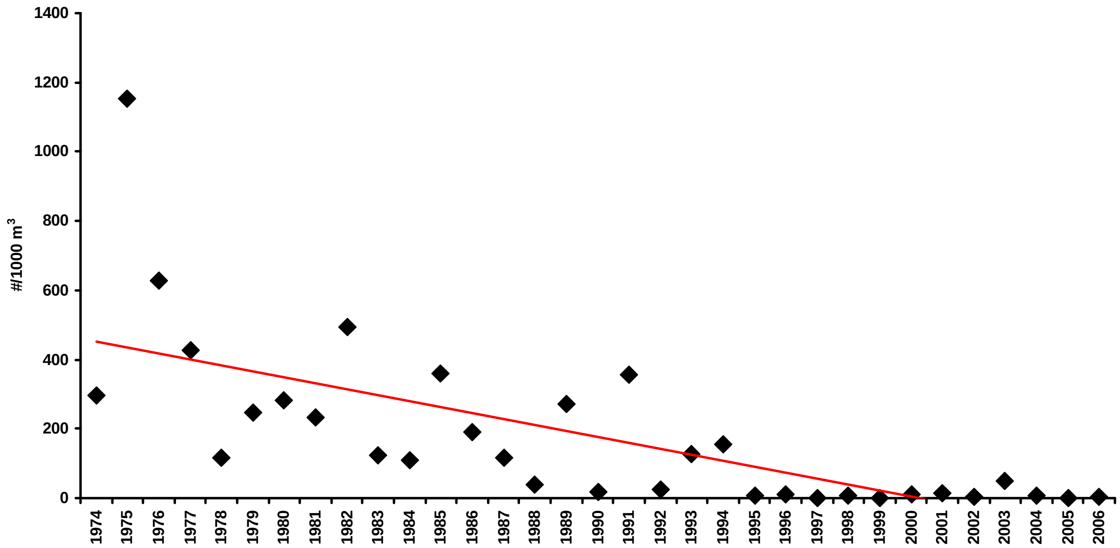


Figure 6. Above shows *Hypsypops rubicundus* larval density (#/1000 m^3) from 1974-2006. Below is a plot of an overlay of this density on the MDS ordination.



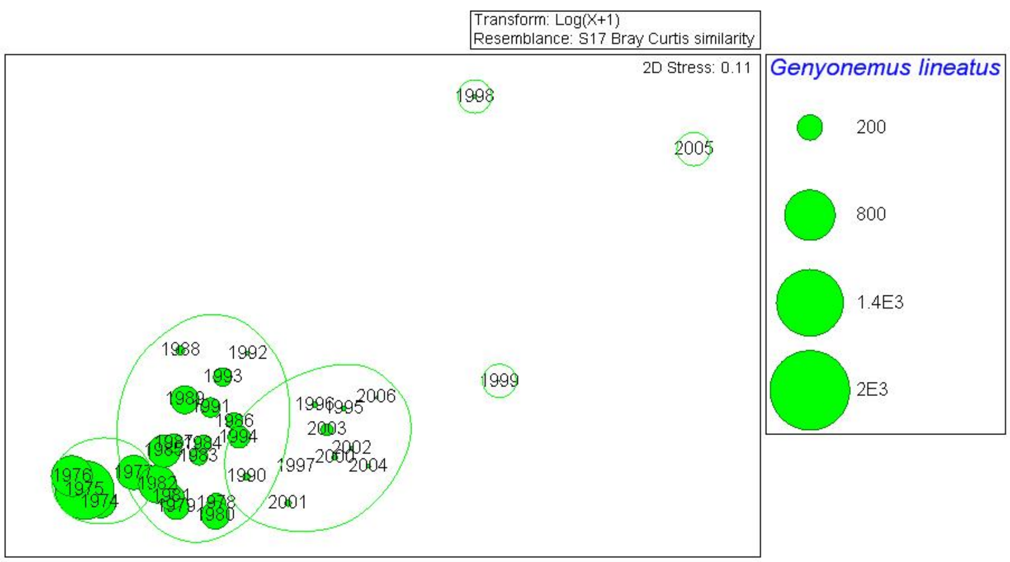
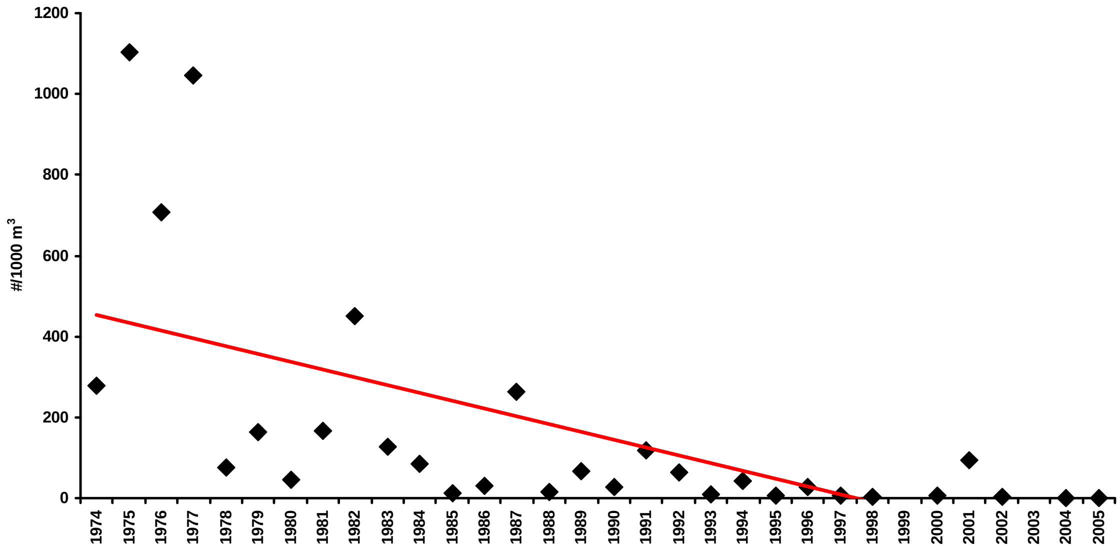


Figure 7. Above shows *Genyonemus lineatus* larval density (#/1000 m^3) from 1974-2006, the regression line is in red. Below is a plot of an overlay of this density on the MDS ordination.



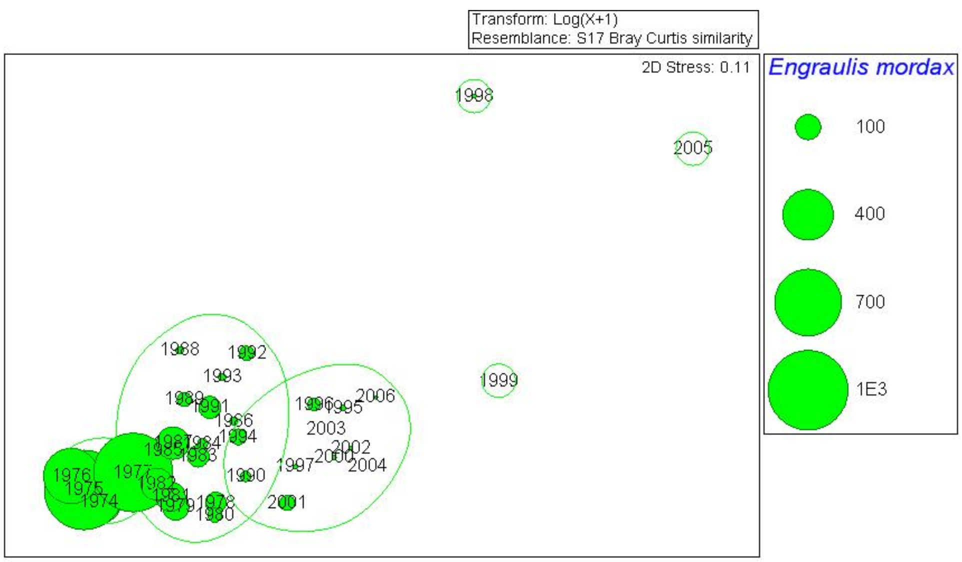


Figure 8. Above shows *Engraulis mordax* larval density (#/1000 m^3) from 1974-2006, the regression line is in red. Below is a plot of an overlay of this density on the MDS ordination.

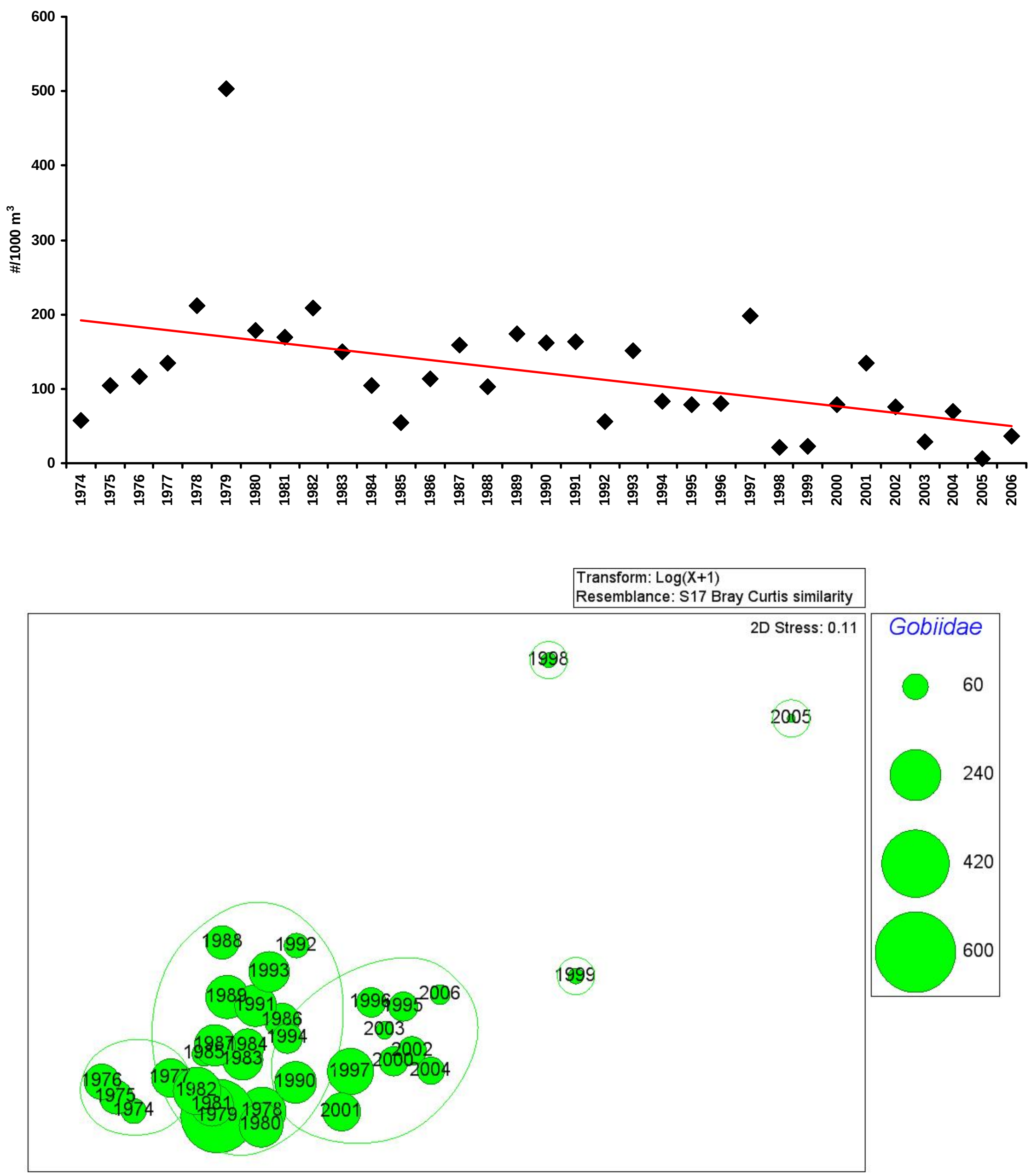


Figure 9. Above shows Goby A/C larval density (#/1000 m^3) from 1974-2006, the regression line is in red. Below is a plot of an overlay of this density on the MDS ordination.

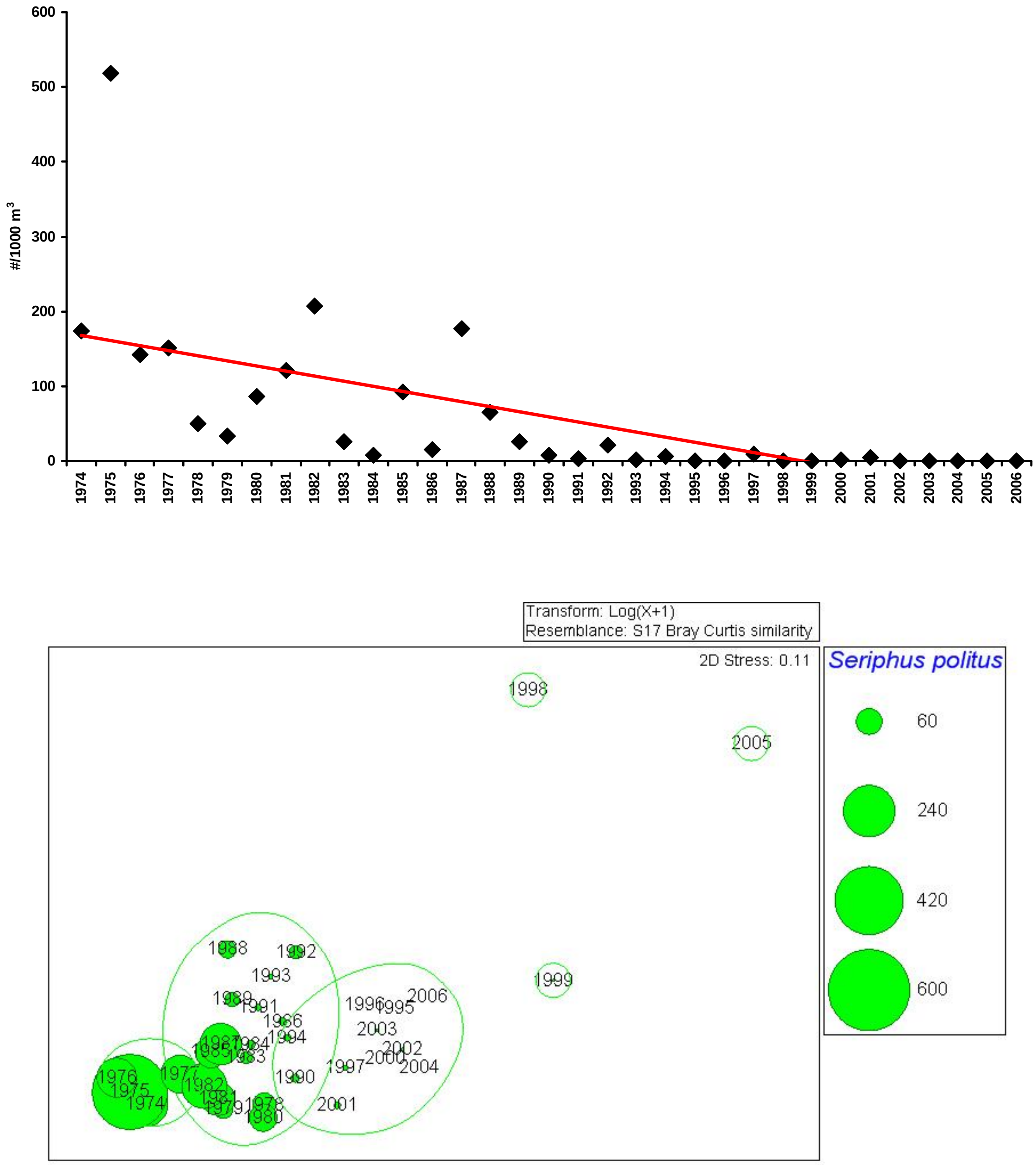


Figure 10. Above shows *Seriphus politus* larval density (#/1000 m^3) from 1974-2006, the regression line is in red. Below is a plot of an overlay of this density on the MDS ordination.

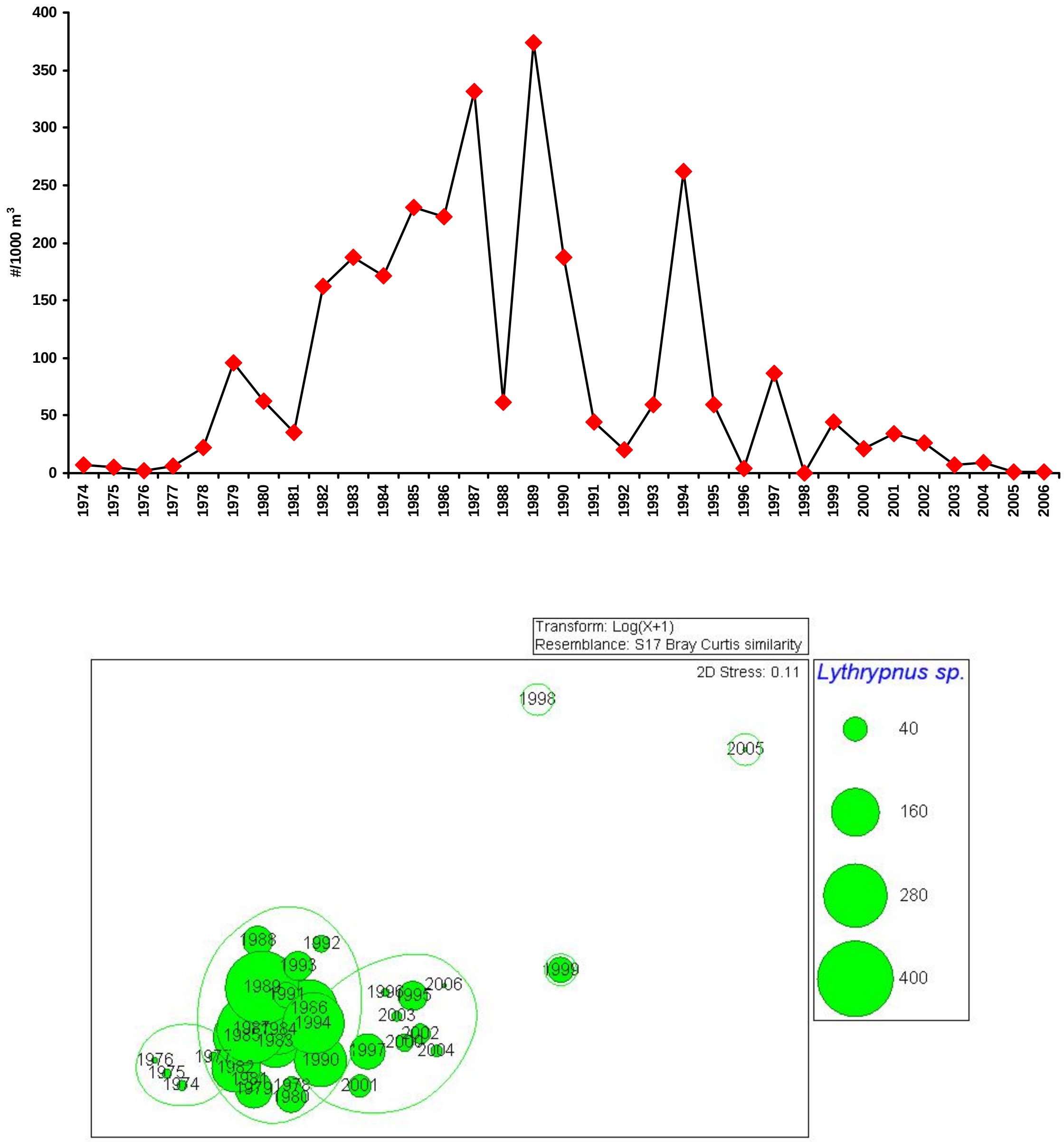


Figure 11. Above shows *Lythrypnus* sp. larval density (#/1000 m^3) from 1974-2006. Below is a plot of an overlay of this density on the MDS ordination.

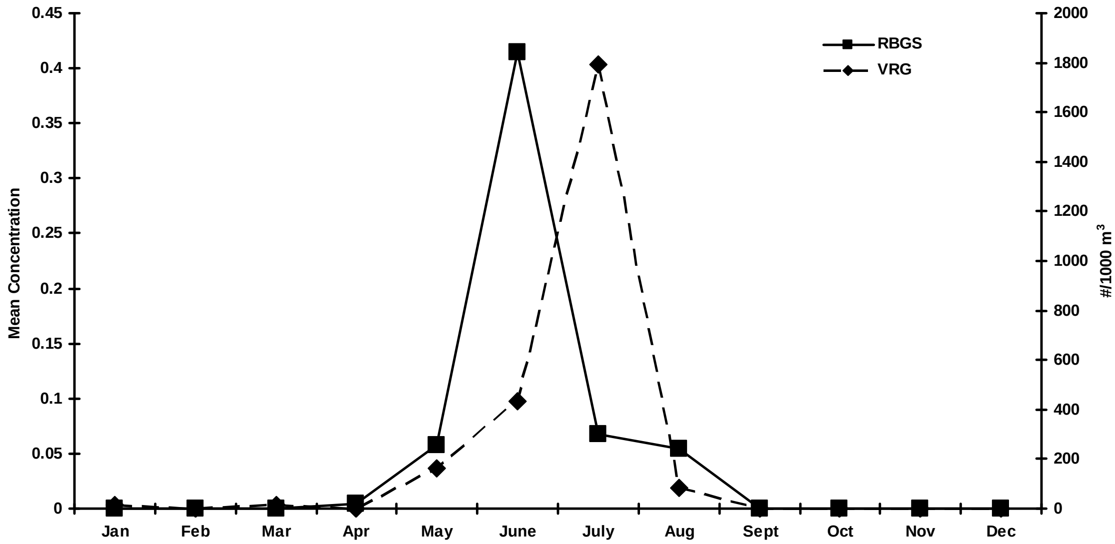


Figure 12. This is a plot of the mean larval catch from the Redondo Generating Station's entrainment survey and the VRG's King Harbor ichthyoplankton study by month in 2006 for *Hypsypops rubicundus*.

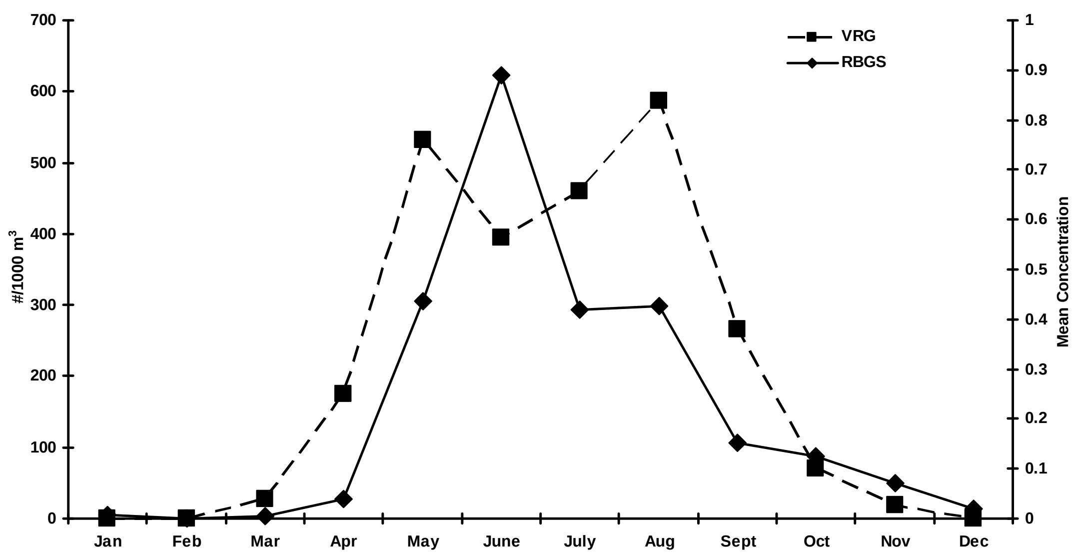


Figure 13. This is a plot of the mean larval catch from the Redondo Generating Station's entrainment survey and the VRG's King Harbor ichthyoplankton study by month in 2006 for *Hypsoblennius sp.*

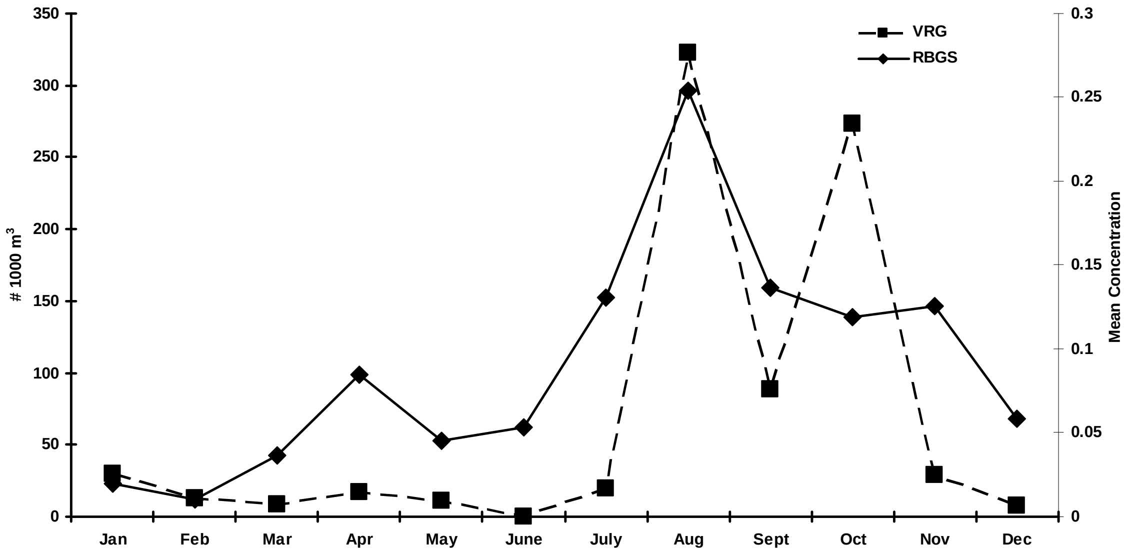


Figure 14. This is a plot of the mean larval catch from the Redondo Generating Station's entrainment survey and the VRG's King Harbor ichthyoplankton study by month in 2006 for Goby A/C species complex.

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Appendix A:
The Mean Annual Density of late stage larvae

Appendix A. The mean annual density (1000 m3) of late stage larvae (FL, SL, LV) from Stations 1 and D, 1974-2006.

Taxa	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Hypsoblennius sp.	2080	1065	530	985	379	823	1247	633	762	410	262
Hypsypops rubicundus				91	290	286	475	57	150	80	37
Genyonemus lineatus	296	1080	521	367	110	199	246	205	445	97	88
Engraulis mordax	278	998	481	979	67	111	32	137	161	74	17
Goby A/C	58	104	117	135	212	503	179	169	209	150	105
Lythrypnus sp.	7	5	2	6	22	96	63	36	163	187	172
Seriphus politus	173	511	141	128	50	33	69	101	183	14	7
Paraclinus integripinnis	39	23	5	26	39	408	40	236	69	26	50
Rhinogobiops nicholsii	39	59	21	6	2	15	48	28	23	19	
Typhlogobius californiensis	21	7	18	33	5	6	22	4	17	15	26
Ruscarius craeseri	3	9	15		3	2	21	9	21	12	7
Sardinops sagax	3	7	36	13		11		1	40	13	9
Paralichthys/Xystreurys	6	20	55	14	9	9	4	14	64	16	17
Lepidogobius lepidus					4	26	17	15	40	25	8
Paralabrax sp.	5	1	27	5		9	1	21	33	5	8
Atherinopsis californiensis			1	10					6		9
Gibbonsia sp.	8	1	2	2	24	26	26	7	5	1	5
Gobiesox rhessodon	1	2	1	1	17	16	22	1	2	4	1
Paralichthys californicus	6	1	1	1		1					
Leuresthes tenuis	3		10	20			1		29		
Pleuronichthys verticalis	4	26	7	12		8	1		7	1	1
Oxylebius pictus	9	19	8		1		1		1	2	1
Menticirrhus undulatus	7	5	16	8		1		7	5	1	
Pleuronichthys guttulatus	3	5	25	2	1	4	1		7	1	3
Atherinops affinis	1		1			16	6	1	0	1	
Neoclinus sp.	5	8	6	13	5	9	15	1	11	1	
Chromis punctipinnis	11					12	14		4	1	
Oligocottus/Clinocottus		1	2	2	3	1	8	9	5	3	4
Syngnathus leptorhynchus					1	4	7	7	5	4	2
Pleuronichthys ritteri		1	7	1		2			5	2	4
Cheilotrema saturnum	4	2	13	3	1	2		7	3	1	2
Citharichthys sp.	1	1	5	5		3		1	10	2	
Sebastes sp.			2			1		1	0		
Sphyraena argentea	19	3	3		1						2
Heterostichus rostratus		5	1		5	1	2		1	1	2
Stenobrachius leucopsarus	3	3	6	10							
Atherinopsidae	5	29									
Engraulidae									21		
Clupeiformes									18		
Sciaenidae	10	1						1	0		1
Roncador stearnsii											
Clinidae	7	5	4	2							
Triphoturus mexicanus					1	1	2		4		
Halichoeres semicinctus	1					2	1		2		

Appendix A. continued.

Taxa	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Scomber japonicus			1				1	4	3		1
Hypsoblennius jenkensi		1							1	1	1
Parophrys vetulus	1	10	2	1							
Scorpaena guttata											
Anisotremus davidsonii	1									1	
Cottidae		2	1	1							
Artedius lateralis		1	2								
Cosmocampus arctus	4		1	4							
Peprilus simillimus	1		1	4					1		
Pleuronectidae									1		
Trachurus symmetricus	4		1		1						
Oxyjulis californica	1	1	3			1	1				
Exocoetidae										3	1
Pomacentridae			1				3		1		
Clinocottus analis	1										
Cypselurus sp.		1									
Syngnathus sp.			1	2							
Chilara taylori			1								
Atractoscion nobilis									1		
Synodus lucioceps				2		1					
Girella nigricans											
Pleuronichthys coenosus							1				
Icelinus/Orthonopias											
Ophidion scrippsae	1		1			1					
Gillichthys mirabilis						1	1				
Myctophidae					1	1					
Agonidae		1									
Semicossyphus pulcher	1										
Merluccius productus											
Pleuronectiformes		1									
Kyphosidae			1								
Icelinus quadriseriatus									1		
Ophidiidae						1					
Bathylagus ochotensis		1									
Medialuna californiensis		1									
Cyclopteridae	1										
Seriola dorsalis	1										

Appendix A. continued.

Taxa	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Hypsoblennius sp.	705	205	481	292	356	805	193	163	105	362	204
Hypsypops rubicundus	111	193	136	43	85	879	45	71	48	353	255
Genyonemus lineatus	330	84	108	26	246	17	123	5	109	153	7
Engraulis mordax	6	10	166	9	32	17	76	33	9	41	5
Goby A/C	55	113	158	103	173	161	163	56	151	83	79
Lythrypnus sp.	231	222	332	61	373	188	44	20	58	262	59
Seriphus politus	89	6	155	28	19	6	4	16	2	4	
Paraclinus integripinnis	20	7	26	3	3	221	3	8	38	6	2
Rhinogobiops nicholsii		2	12	145	115	56	22	3	3	30	24
Typhlogobius californiensis	33	72	40	7	1	22	5	18	2	18	15
Ruscarius craeseri	5	23	7	2	42	29	10			10	51
Sardinops sagax	53	76	44	33	8	11		4	13	21	
Paralichthys/Xystreurys	95										
Lepidogobius lepidus	6	8	7			1	2	11	5	10	
Paralabrax sp.	28	2	21	7	1	3	6		4	1	
Atherinopsis californiensis	18	1	13		8	1	1		19	1	1
Gibbonsia sp.	3	5	6		8	4	2	2	2	5	6
Gobiesox rhessodon	4	2	4			38	1	1	2	3	2
Paralichthys californicus	1	22	23	2	8	4	14	5	7	16	1
Leuresthes tenuis			1			5					
Pleuronichthys verticalis	7	4	6	1	7		7		1	1	
Oxylebius pictus	1				2	2	2			1	
Menticirrhus undulatus	5		9	3	3	2		15	4		
Pleuronichthys guttulatus	1	3	1		3				2	2	3
Atherinops affinis				1		4		1			45
Neoclinus sp.						1					
Chromis punctipinnis			2	7	22			1			
Oligocottus/Clinocottus	3	2			1	3	2	1	1	8	
Syngnathus leptorhynchus	6		3	2	5	2	3		1	2	2
Scorpaenichthys marmoratus				24	2		1			2	1
Pleuronichthys ritteri	2	2	6	1	5	1	2	1		4	1
Cheilotrema saturnum	2		2			1	1				
Citharichthys sp.	1	2	2		4	1	4			1	
Sebastes sp.		1				1	1				1
Sphyraena argentea	1		2	3		1	14				
Heterostichus rostratus	4	1		3		2					
Stenobrachius leucopsarus							1				2
Sciaenidae	4		2								
Triphoturus mexicanus	3	3									
Halichoeres semicinctus	1		4			1	1				
Scomber japonicus	1		1	1							
Hypsoblennius jenkensi		2									
Scorpaena guttata						14					
Anisotremus davidsonii			1	5		1					
Cottidae							1	5			
Pleuronectidae	1		2				2				
Trachurus symmetricus								1			

Appendix A. continued.

Taxa	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Pomacentridae		1									
Cypselurus sp.							1	1	1		1
Syngnathus sp.				1							
Chilara taylori							1	1		2	
Atractoscion nobilis				5			1				
Citharichthys stigmaeus							4				
Synodus lucioceps			1								
Girella nigricans				5	1	1					
Pleuronichthys coenosus											
Icelinus/Orthonopias				4				1			
Ophidion scrippsae			1								
Umbrina roncador			2								
Artedius sp.				1							
Xystreurys liolepis			1								
Lythrypnus dalli							1				
Symphurus atricaudus											1
Paralabrax maculatofasciatus				1							
Lyopsetta exilis					1						

Appendix A. continued.

Taxa	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Hypsoblennius sp.	249	1129	12	223	309	748	424	420	677	38	262
Hypsypops rubicundus	200	945	3	250	329	549	292	306	400		94
Genyonemus lineatus	10		5	1	11	13	3	47	5		3
Engraulis mordax	26	3	3		4	36	2				2
Goby A/C	80	198	21	23	79	134	76	29	69	6	37
Lythrypnus sp.	4	86		45	21	35	27	7	9	1	1
Seriphus politus		2		1		4	1	1			
Paraclinus integripinnis	23	79			9	19	13	4	10		18
Rhinogobiops nicholsii	4	36			24	93	109	22	30		7
Typhlogobius californiensis	22	13	9	20	60	59	42	29	24	1	9
Ruscarius craeseri	13	4	7	1	95	11	14	27	69	5	5
Sardinops sagax		1							1		1
Lepidogobius lepidus	2				1		2	4			
Paralabrax sp.		1						1			
Atherinopsis californiensis	34	8		6	32	1	11	13	4	1	7
Gibbonsia sp.	3	2			5	30	13	4	3		4
Gobiesox rhessodon	8	9		1	3			2	2		1
Paralichthys californicus		4			6				3		1
Leuresthes tenuis		2				25	1		1	3	16
Pleuronichthys verticalis	1	1				3	1	1			
Oxylebius pictus					4	3	5	2	35		6
Menticirrhus undulatus		2			1			1	2		
Pleuronichthys guttulatus	3	7	1		1		1	1		2	2
Atherinops affinis	1	1			16	4	4	1		1	3
Neoclinus sp.						5					
Oligocottus/Clinocottus	1	1		1	1	1					1
Syngnathus leptorhynchus	1	1			1	2	1	1	1	2	1
Scorpaenichthys marmoratus	2				4		15	7	9		3
Pleuronichthys ritteri		1			1				1		
Cheilotrema saturnum		2			3			1			
Citharichthys sp.							1	1			
Sebastes sp.					24	3	9		12		
Sphyraena argentea											
Heterostichus rostratus				2	1	1	4	1			1
Stenobrachius leucopsarus								4			
Atherinopsidae				1							1
Sciaenidae	1					1					
Roncador stearnsii							1	15	1		1
Clinidae							1				
Hypsoblennius jenkensi	1	2									1
Anisotremus davidsonii								4			
Cottidae					1						
Artedius lateralis								5	1		
Exocoetidae		1									
Clinocottus analis					2	1		1	2		
Cypselurus sp.	2										
Xystreurys liolepis							1				
Merluccius productus											1
Menidia beryllina			1								
Chaenopsis alepidota							1				